Essay

Analysis of space-time environmental indicators of water, soil and vegetation

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Abstract

Environmental indicators are of the utmost importance because they provide quantitative and qualitative information to assess the use, availability and alteration of natural resources. The objective of this essay was to review from 2006 to 2018 environmental indicators with a spatial and temporal approach, used to assess the environmental condition. Subsequently, the information consulted was classified into three main groups of water, soil and vegetation indicators. After the potentialities of the different methods of environmental indicators were determined, within these relevant findings it was observed that each methodology depends on the quality of the information and the objectives of each study. Among the methodologies analyzed, the most relevant due to the precision of their results, were the indices of vegetation and multicriteria analysis, since it allows to explicitly perceive the parameters of the area that have been modified by human activities. It is concluded that the environmental indicators methodologies depend on the spatio-temporal aspect and the quality of the data, as well as the natural resource to be evaluated.

Keywords: analysis scale, methodologies, multicriteria analysis, natural resources, vegetation index.

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Environmental problems seriously affect natural resources due to the activities of human beings (Walz, 2015). In the literature reviewed, it has been shown that environmental indicators are used to assess the 'health' of ecosystems (Luo, Huai and Gao, 2017) because they are fundamental instruments for generating, storing and analyzing information (Rodríguez *et al*., 2013; Schindler *et al*., 2015; Gao *et al*., 2017).

An indicator describes situations of a space at a given time, that is, they are space-time indicators (Nowak and Schneider, 2017; Pratama *et al*., 2017; Bao and Zou, 2018) that provide, condemn, systematize and order quantitative information or qualitative (Schindler *et al.*, 2015; Li *et al.*, 2016; Bao and Zou, 2018). The environmental indicators present guidelines, statistics, classification categories and predictive situations, which provide signs of possible future scenarios (Rodríguez *et al*., 2013; Wen *et al*., 2017) which must be practical and realistic (Walz, 2015; Turner *et al*., 2016).

This review provides a classification of three main groups of environmental indicators of water, soil and vegetation, as well as a spatial-temporal conceptual basis applied for the visualization, evaluation and modeling of multipurpose data towards decision-making (Xu and Zhang, 2013; Klug and Kmoch, 2015; Echavarren, 2017).

Temporary space environmental indicators

The intention of this document is not to open a deep and detailed discussion about the theoretical and practical approaches related to environmental indicators, rather it is to show different works where space-time environmental indicators have been used to know the situation of the environment in the that different methodologies were applied to assess the situation of ecosystems (Bredemeier *et al*., 2015; Turner *et al.*, 2016; Dyer *et al*., 2017; Zhang and Xu, 2017).

Unquestionably, space-time environmental indicators are a broad and diverse issue, which the authors have used to evaluate ecosystems, their dynamics, as well as environmental management applications (Luo *et al*., 2017).

Recent research shows that environmental indicators present useful data and comparisons to contribute to the sustainability of nature, in decision-making and environmental policy formulation (Alphan, 2017; Neher *et al*., 2017; Nowak and Schneider, 2017; Pratama *et al*., 2017) and constitute a basic tool for information and monitoring of processes that originate in the natural, social and economic environment (Xu and Zhang, 2013; Asumadu-Sarkodie and Owusu, 2017; Sinha *et al*., 2017).

The environmental indicators monitor the biophysical and socioeconomic environmental impact, recognized as a fundamental need at local, regional, national and even international level (Neher *et al*., 2017; Sinha *et al*., 2017). Evaluate the environmental impact through innovative and precise tools to predict the consequences of development (Klug and Kmoch, 2015; Arnaiz-Schmitz *et al*., 2017; Han *et al*., 2017) providing useful information for planning when presenting updated data and comparisons (Alphan, 2017; Gao *et al*., 2017; Luo *et al*., 2017; Bao and Zou, 2018).

Based on the above, it was determined that environmental indicators are basic tools for information and monitoring of processes that occur in the natural, social and economic environment, to know the status and trend of natural resources (Xu and Zhang, 2013; Asumadu-Sarkodie and Owusu, 2017; Sinha *et al*., 2017). In addition, they provide information in a simple and easy way to understand statistically; through a model or set of assumptions that relate the indicator to more complex phenomena (Walz, 2015; Neher *et al*., 2017) communicating scientific and technical information based on environmental issues (Schindler *et al*., 2015; Turner *et al*., 2016).

Therefore, environmental indicators focused on natural resources measure and evaluate the quality of the environment (Walz, 2015; Shrestha *et al*., 2017) define their use and exploitation, with the purpose of reducing pollution or degradation of nature (Park *et al*., 2015; Neher *et al*., 2017; Nowak and Schneider, 2017).

Applications of environmental indicators

Because the information used to construct space-time environmental indicators is broad and diverse, a conceptual framework is required to structure information and ease of access and interpretation (Azadeh *et al*., 2017; Bao and Zou, 2018), it is essential to review and evaluate different works on environmental indicators to know the importance of natural resources in a space-time analysis of each study and define the most effective methodologies (Luo *et al*., 2017; Nowak and Schneider, 2017). Based on the characteristics of each method, the information consulted was classified into three main groups: environmental indicators of water, soil and vegetation.

Water indicators

Water is essential to guarantee the integrity and sustainability of terrestrial ecosystems (WWAP, 2017), being one of the most important resources for life on the planet since all living beings, including humans, depend on their availability to its operation despite its importance, it is a scarce, threatened and endangered resource, water extraction, pollution and access has increased (Vollmer *et al*., 2016; WWAP, 2017).

From the different works of environmental indicators focused on the study of water Klug and Kmoch (2015) generated, evaluated and modeled multipurpose data of indicators in order to perform immediate actions in times of crisis to monitor water flows and extractions with spatial information in a global analysis scale they described new ways of processing indicators using wireless sensor networks and standardized web services.

Standardized environmental information was automatically incorporated into web processing services for timely delivery of information, discovery and access to spatial environmental conditions. Said monitoring of water flows and withdrawals was carried out in order to ensure the timely provision of spatial information to reduce the delay times in the water supply.

Meanwhile, Vollmer *et al*. (2016) developed and evaluated indices that measure the ecological health of water, observing that as stress factors in water systems increase in magnitude and abundance, information needs and the ability to manage water systems change according to Spatial scale of analysis (local to global). Therefore, they determined that quantitative indicators are a common means to assess the dimensions of a water system and provide scientific knowledge for decision makers and policies.

On the other hand, Gao *et al*. (2017) analyzed environmental indicators on a regional spatial scale of precipitation, evapotranspiration and observed that precipitation increases significantly. However, evapotranspiration showed a non-significant decreasing trend. While, the precipitation showed an evident evolution, growth and tendency in the change of the climate according to the model.

Based on the above, the indicators allowed us to determine that water resources will increase with global warming. From the temporal perspective, it presented a slightly decreasing trend in precipitation and a significant increase from the spatial perspective.

Regional scale

Meanwhile, Shrestha *et al*. (2017) They used indicators on a regional spatial analysis scale with an analysis of variance to reduce environmental impacts and improve water quality related to nutrients in wetlands by agricultural activities, detecting many significant interactions of time and by type of flow in wetland areas, as well as several parameters and total habitat scores that showed a general improvement of wetlands as opposed to agricultural areas. The habitat parameters evaluated significantly improved wetlands, although not always steadily throughout the year.

Bao and Zou (2018) on a regional spatial analysis scale assessed the integral dynamics of temporal and spatial variability of water resources. They applied a system of integral and dynamic evaluation determined by thresholds and norms through a hierarchical structure to calculate weights and establish a multi-objective approach; through, normalized values of the space-time characteristics between water scarcity and human activities.

The spatial and temporal changes of the water indicators analyzed show a great disparity in the relationship between man and water, which is determined by the scarcity of water and human activities over time (Table 1).

Table 1. Environmental indicators of water.

Analysis scale*	Spatial data	Method used	Author
Regional	Natural region and degree of efficient use of water resources	Analytical model of hierarchy process	Bao and Zou (2018)
Global	Wireless sensor networks and standardized web services	Real-time multipurpose modeling	Klug and Kmoch (2015)

Analysis scale*	Spatial data	Method used	Author
Regional	Monthly monitoring of water flows in the basin	Variance analysis	Shrestha *et al.* (2017)
Local	95 water indices	Risks evaluation, driving forces-Pressures-state-impact-response (DPSIR)	Vollmer *et al.* (2016)
Regional	Precipitation, potential evapotranspiration, standardized precipitation evapotranspiration index	Comparison model	Gao *et al.* (2017)

*= Global, regional, local and landscape

Soil indicators

The soil is a natural and vital resource for the human being but due to human activities, self-regulation and balance have been altered, causing serious environmental problems (Yu and Xudong, 2016; Azadeh *et al*., 2017) such as quantity, quality, goods and services (Xu and Zhang, 2013). The environmental indicators of the soil determine the space-time changes (Xu and Zhang, 2013; Zolekar and Bhagat, 2015) in order to guide the activities of the human being for a balance with nature.

Regarding the environmental indicators of the soil, a relevant work is by Ligmann-Zielinska and Jankowski (2014) in which they describe a scale of local spatial analysis and multicriteria space-time sensitivity to assess the suitability and suitability of the soil through weights that express distributions of habitat probability characterizing to define the inclusion and exclusion of areas with aptitude in the use of the land.

Alphan (2017) on the other hand, on a spatial scale of landscape analysis and with the patch index methodology, defined guidelines to know the changes focused on agricultural areas and urban areas, highlighting a great spatial, seasonal and temporal diversity. Determining that the shapes and sizes of each variable of the different land cover categories increase spatial diversity, as well as crop rotation and the change in vegetation phenology have an impact on seasonal diversity.

Therefore, the adequate understanding of the spatial and temporal characteristics of this environmental attribute is of vital importance as it reveals the causes of environmental problems and addresses the consequences of poor soil management.

Meanwhile, Asumadu-Sarkodie and Owusu (2017), using a linear regression model, defined the impact of land use change through environmental indicators on a local analysis scale, which play an important role in the sustainability of the ground. However, agricultural methods and practices that seem unsustainable still play a fundamental role in farming communities. Therefore, the introduction of modern agricultural practices in local and regional communities through awareness raising would contribute to the fight against climate change.

Nowak and Schneider (2017), for their part, identified areas threatened and degraded by agricultural activity through environmental indicators on a regional analysis scale, defined by soil erosion, nutrient loss and groundwater contamination. The results show that the areas most threatened by agricultural activity are located in the mountainous region, while most of the degraded areas were located at the bottom of the valleys and in areas with intensive agriculture.

The slope and use of land also played an important role in the case of loss of soil and nutrients. This method provided spatially specific data on the areas affected by the degradation processes and determines that the soil is a good indicator to know the environmental problems.

While Yu and Xudong (2016); through ecological indicators on a scale of regional analysis, they established the suitability of the soil through ecological sensitivity, vegetation cover, soil quality and the atmospheric environment, among other factors. According to the soil situation, they found that the choice of these indicators is the most common and integral factor for the protection of ecological areas, vegetation, soil, air, water, etc., due to their fragile environmental situation. Therefore, environmental indicators play an important role in establishing the index system for assessing soil suitability.

From the different environmental indicators reviewed, the importance of having space-time soil indicators to assess environmental problems and support decision-making was observed (Table 2).

Table 2. Environmental indicators of the soil.

Analysis scale*	Spatial data	Method used	Author
Landscape	Spatio-temporal changes in land cover	Patch Index (LPI)	Alphan (2017)
Local	Land-use change	Least squares regression model	Asumadu-Sarkodie and Owusu (2017)
Local	Criteria weights	Analysis of uncertainty and spatial sensitivity	Ligmann-Zielinska and Jankowski (2014)
Regional	Agricultural areas, soil erosion, loss of nutrients and water pollution	Model of soil loss and erosion	Nowak and Schneider (2017)
Regional	Ecological sensitivity, vegetation cover, soil quality, atmospheric environment	Ecological index	Yu and Xudong (2016)

*= Global, regional, local and landscape.

Environmental indicators of vegetation

Biodiversity worldwide is being lost at an unprecedented rate despite the fact that in recent decades progress has been made in its conservation on a global scale. Vegetation being an important element in biodiversity, since it plays a fundamental role for conservation, soil protection, carbon sequestration, among others. Therefore, through the environmental indicators we seek to know the diversity of the vegetation and its changes over time (Zolekar and Bhagat, 2015; Turner *et al*., 2016; Wen *et al*., 2017; Zhang and Xu, 2017).

From the methodologies analyzed Romero-Calcerrada and Luque (2006) on a spatial scale of local analysis evaluated the biodiversity of the landscapes in a forest from a multicriteria analysis that predicted the suitability of a habitat with indicator species based on environmental and vegetation characteristics, by combining remote sensors and field data.. The model is a quantitative multicriteria method used to combine different species information. The method depends on the indicator species and biodiversity conditions of the protected areas, defined by a range of probability of occurrence; through an objective assessment of habitat fitness.

Bredemeier *et al*. (2015) on a regional spatial analysis scale determined the value of the conservation of the nature of different habitats based on the richness of species from territorial units and described their quantitative effects on biodiversity and nature conservation with the use of different spatio-temporal scales. Where the spatial scale of the indicators allows the application of a model through a geographic information system.

The model evaluated the level of conservation of habitats based on the effects on the landscape of the flora with pressure indicators and modifies the value of conservation of crop field density and the variation in pressure changes of the Agriculture.

Meanwhile, Dyer *et al*. (2017) on a regional spatial analysis scale, they evaluated the biodiversity of rare and threatened species and habitats based on an indicator based on spatio-temporal patterns, which shows the relationship between the ecological status of areas determined by unique species and defined that a threatened species does not establish the pressure of that species on the ecological state of biodiversity, since they require evaluation and prioritization through spatial and temporal analysis. Establishing that, environmental impact indicators are important tools for predicting development progress and changes in land use.

While, Li *et al*. (2017) On a scale of local spatial analysis, the combination of land cover and trends of change in the normalized vegetation index identified ecological performance, based on soil cover where the results show an evident increase in these changes and indicate that ecological restoration is experiencing increasing challenges due to the growing human activity and the fragile ecological environment.

While, Wen *et al*. (2017) analyzed the changes of the vegetation based on anthropogenic factors of population density, artificial ecological restoration and urbanization on a spatial scale of regional analysis, in order to determine the impact of human activities on the vegetation through data from different times of changes in the ecosystem.

Analyzing the space-time patterns, they determined that anthropogenic factors have impacts on vegetation, as well as climatic factors. Information on the space-time indicators of vegetation is of the utmost importance for the study of the environment, specifically of biodiversity (Table 3).

Table 3. Environmental indicators of vegetation.

Analysis scale*	Spatial data	Method used	Author
Regional	Type of crop and flora species richness	Models of territorial units	Bredemeier *et al*. (2015)
Regional	Endangered species, spatial and temporal patterns	Biodiversity model	Dyer *et al*. (2017)
Local	Vegetation cover	Analysis of land cover and trends of change in the normalized vegetation index	Li *et al*. (2017)
Local	Weights	Multicriteria analysis	Romero-Calcerrada and Luque (2006)
Regional	Interannual changes of vegetation	Vegetation index (Pp, Tº, radiation)	Wen *et al*. (2017)

*= Global, regional, local and landscape.

In general, the spatial and temporal changes of the environmental indicators of the water, soil and vegetation analyzed have similar characteristics in the need to define the study area, model and temporality to be analyzed, together with the importance of having quality and precision of the data.

Spatio-temporal analysis of environmental indicators

In recent decades, tremendous progress has been made in the analysis, characterization and compression of environmental processes, functions and structures through environmental indicators. However, many of the approaches are based on specific case study areas and the transfer of approaches is hampered due to incompatible and available data formats. In addition, the environmental modeling provided by environmental indicators changes continuously, mainly due to technological and methodological advances (Klug and Kmoch, 2015).

Therefore, the continuous development of indicators shows the need for new and better ways of assessing the current situation of natural resources of water, soil and vegetation, as well as synthesizing accurate and detailed information (Vollmer *et al*., 2016) which It changes according to the space-time characteristics of environmental degradation and human activities (Bao and Zou, 2018).

Although there is a great diversity of articles on space-time environmental indicators, it has not been possible to emphasize any definitive methodology for the study of natural resources. Therefore, it is necessary to know different methodologies to adapt the environmental problem that is faced, as well as to know the importance of the technologies and the information available for the study of the environment, since the adequate understanding of the space-time characteristics of this attribute Environmental, it is of vital importance in the decision-making process to deal with environmental problems through good management (Alphan, 2017).

Mainly because the indicators are efficient to assess the impacts of natural resources caused by the activities of human beings (Bredemeier *et al*., 2015; Alphan, 2017; Bao and Zou, 2018). The type of analysis to be used as an environmental indicator should quantify different variations, oriented towards the management of conservation and use of nature in the integration with the diversity of habitats and natural resources (Ligmann-Zielinska and Jankowski, 2014; Arnaiz-Schmitz *et al*., 2017; Bao and Zou, 2018).

An environmental model of environmental indicators is usually applied to territorial (spatial) units in a certain (temporary) scenario with possible effects (Walz, 2015; Zolekar and Bhagat, 2015). Where, the spatio-temporal analysis demonstrates a great variation of natural resources (Schindler *et al*., 2015; Dye *et al*., 2017) both within the study area and the local and regional environmental zones.

From the methodologies analyzed in this document, it was observed the need to continue working on the generation of knowledge attached to reality to define predictive models that are reliable and comparable to reality (Romero-Calcerrada and Luque, 2006; Li *et al*., 2017).

Through an objective evaluation of space-time environmental indicators for each natural resource that provides solid information through the simulation of processes and criteria for decision-making (Romero-Calcerrada and Luque, 2006; Ligmann-Zielinska and Jankowski, 2014) since, the ways of measuring and balancing the needs and uses of natural resources are essential to understand and manage them properly.

With respect to the environmental indicators examined, the majority focuses on natural resources as scarce or in high demand and with a great dependence on the part of the human being. Therefore, the credibility or scientific and technical rigor of an indicator is the main focus of the review, since the theoretical-methodological aspects of scientific, technological and social values play an important role in the application of each indicator environmental.

Conclusions

The environmental indicators monitor, analyze and report on environmental conditions and changes through interdisciplinary integration at local and regional level in accordance with the available environmental information of each case study, in order to evaluate and facilitate the understanding of the complexity of nature; through the quantification of environmental benefits or impacts.

Each environmental model of environmental indicators must comply with national and international standards to ensure interoperability, comparability, transferability and integration of information, since there is a large number of environmental indicators in use, but a considerable variation in what is measured and how each indicator is applied, making it difficult for end users to identify the appropriate evaluation methods.

Currently, with the support of technologies, there are different methods to generate and analyze space-time environmental indicators with timely information but there is still a lot to generate information that shows the real-time situation of each environmental problem.

The environmental indicators of water, soil and vegetation are defined by the spatio-temporal changes of the study area, the quality and precision of the data to be used.

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